A COMPLETE COMPUTER PROGRAM FOR THE SYNTHESIS OF MATCHING NETWORKS FOR MICROWAVE AMPLIFIERS

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Abstract

A complete computer program has been developed for the design of interstage matching networks for microwave amplifiers using (generalized) passive network synthesis which has been generalized to provide sloped passband performance, inclusion of parasitic elements and transformation of impedance levels.

I. Introduction

The theory of a complete computer program developed for the design of interstage matching networks for microwave amplifiers[1] using generalized passive network synthesis will be described. A procedure for obtaining matching networks of arbitrarily sloped frequency response is developed and provision for the inclusion of parasitic elements into synthesized networks is made. An interactive computer routine implements the synthesis of matching networks to the user-specified passband, ripple and desired frequency slope and adjusts the relative gain of the frequency response to insure inclusion of specified parasitic elements. Further, the computer routine lists all available topologies, performs impedance transformations and uses a transformed variable to enhance synthesis accuracy.

II. Characteristics of the Interstage Design Problem

Typical amplifier specifications call for a good input and output match and for an overall amplifier transducer gain which is constant (flat) over the passband. These specifications determine the impedance and frequency response characteristics of amplifier matching networks as illustrated in Figure 1. The active devices are assumed unilateral and the input and output impedances of these active devices are modelled in lumped element form such that independent design of matching networks is possible. In general, each matching network operates between arbitrary impedances and must exhibit a flat or sloped frequency response as explained in the following comments:

a) The gain of transistors at microwave frequencies generally decrease with increasing frequency.

b) The specification for good input and output match implies a frequency response of the input and output matching networks that is flat over the passband.

c) The interstage matching networks (in general, there may be more than one) must provide a positive-sloped gain with frequency in order to compensate the transistors' roll-off and give on overall flat transducer gain.

III. Outline of Proposed Solution: Matching Synthesis

The procedure here described for the synthesis of matching networks of arbitrarily-specified passband slope with provision for inclusion of parasitic elements is called MATCHING SYNTHESIS[1] and is outlined in Figure 2.

IV. Key Developments of the Matching Synthesis Procedure

The Sloped Approximation Problem

Passive network synthesis is a well known procedure whereby a passive network is obtained from a rational function of the frequency variable that describes the desired frequency response.[2] The passive network so obtained has the exact frequency response of the specifying polynomial function of frequency. The familiar passive network synthesis procedure is described by Figure 3 a) and the following comments:

1) Since the desired square-edged response is not possible with a finite number of elements, a rational approximation of the desired response is made. Approximating an ideal desired response with a rational function of frequency is called the approximation problem in network synthesis, and standard solutions exist for approximating a flat passband performance.

2) In the synthesis procedure, straightforward computational procedures yield a network whose frequency response is that of the specifying rational approximation.

In order to obtain matching networks for amplifiers of overall flat transducer gain, matching networks must be designed which exhibit sloped frequency response, as indicated by Figure 3 b). The general solution to the sloped approximation problem, allowing arbitrary response parameters such as slope, bandwidth, ripple and network order, is essential to the synthesis of matching networks must compensate for the gain roll-off of the active devices with frequency.

Several authors have indicated the need for a solution to the sloped approximation problem[3-5]. Ku et. al.[4] has reported a solution, but the method of solution is not yet published.

Rational approximating functions having 6S dB/octave passband slope (S=integer) are easily derived from flat approximations through division by ω^{2S}:

Flat Insertion Loss $\div\ \omega^{2S}$ = > Sloped Insertion Loss

$$\text{or } IL_F \div \omega^{2S} = IL_S \qquad (1)$$

This procedure will be illustrated in the example to follow.

Rational approximating functions having 6S dB/octave passband slope where S is non-integral can also be obtained.[1]

Inclusion of Parasitic Elements

The presence of parasitic elements limits the available gain bandwidth of a matching network[6] and this available gain bandwidth product must not be exceeded in the synthesis specification if inherent parasitic elements are to be absorbed into synthesized networks. Since the bandwidth and ripple of a design are generally fixed, the gain of the specifying insertion loss is adjusted to ensure absorption of parasitic elements:

$$IL_{SP} = K^2 IL_S \qquad (2)$$

This adjustment procedure is illustrated in our example.

CAD Implementation of MATCHING SYNTHESIS

The rapid and accurate design of matching networks by synthesis methods is best accomplished by an interactive CAD program. The computer-aided implementation of MATCHING SYNTHESIS represents a unique total package for synthesis of matching networks including:

a) Generation of sloped polynomial approximations of arbitrary slope.
b) Adjustment of the frequency response to assure inclusion of parasitic elements into a synthesized network.
c) Generation of all allowable toplolgies for a given synthesis specification.
d) Time-shared synthesis capability up to 12^{th} order utilizing Ø-plane synthesis.[7]
e) Automated implementation of impedance transformations.

V. Example: Matching Network of Sloped Frequency Response

An interstage network is to operate between a 50Ω source and a series 10Ω and .82 pF load. 6 dB/octave gain slope and 1 dB of ripple is required in a 1 to 2 GHz passband.

First a flat insertion loss (IL_F) will be derived using standard approximation techniques, then this insertion loss will be divided by ω^2 to obtain a sloped insertion loss (IL_S) and finally the sloped insertion loss is multiplied by a constant to obtain an insertion loss that will absorb the prescribed parasitic (IL_{SP}). From IL_{SP} the network will be synthesized.

$$IL_F = 1 + K_1 C_2^2 \left(K_2 \left(\omega/\omega_0 - \omega_0/\omega\right)\right)$$

$C_2(X)$ = 2nd order Chebyshev Polynomial = $2X^2-1$

The frequency normalization is taken such that the upper cut-off frequency is scaled to 1 rad/sec.

$\omega_U = 1$ rad/sec. $\omega_L = .5$ rad/sec.

$\omega_0 = \sqrt{\omega_U \omega_L} = .707$ rad/sec.

K_2 sets the relative bandwidth:

$K_2 (\omega_U/\omega_0 - \omega_0/\omega_U) = 1 => K_2 = 1.414$

K_1 adjusts the Ripple: $K_1 = 10^{.1} - 1 = .26$

$$IL_F = \frac{16.6\omega^8 - 37.3\omega^6 + 30.3\omega^4 - 9.3\omega^2 + 1.04}{\omega^4}$$

$$IL_S = IL_F/\omega^2 = \frac{16.6\omega^8 - 37.3\omega^6 + 30.3\omega^4 - 9.3\omega^2 + 1.04}{\omega^6}$$

$$IL_{SP} = K^2 IL_S$$

The value of $K^2 = 1.26$ is sufficient to ensure absorption of the specified parasitic:

$$IL_{SP} = \frac{20.9\omega^8 - 46.9\omega^6 + 38.1\omega^4 - 11.7\omega^2 + 1.3}{\omega^6}$$

The network synthesized from this insertion loss and scaled to 2 GHz upper cut-off is shown in Figure 4 along with the plotted response of the network (IL_{SP}). IL_F and IL_S are plotted also for comparison.

A complete amplifier designed using Insertion loss synthesis methods has been reported.[8]

VI. Conclusion

The powerful tool of passive network synthesis has been generalized to provide a sloped frequency response and to allow absorption of parasitic elements. With these generalizations matching networks can be synthesized in a straightforward, step by step procedure which is quickly accomplished via a CAD routine.

From a user specified bandwidth, slope and ripple, the CAD program provides the configurations and element values of the matching networks and implements impedance transformations necessary for proper termination. Thus matching network design can be accomplished rapidly and accurately.

VII. References

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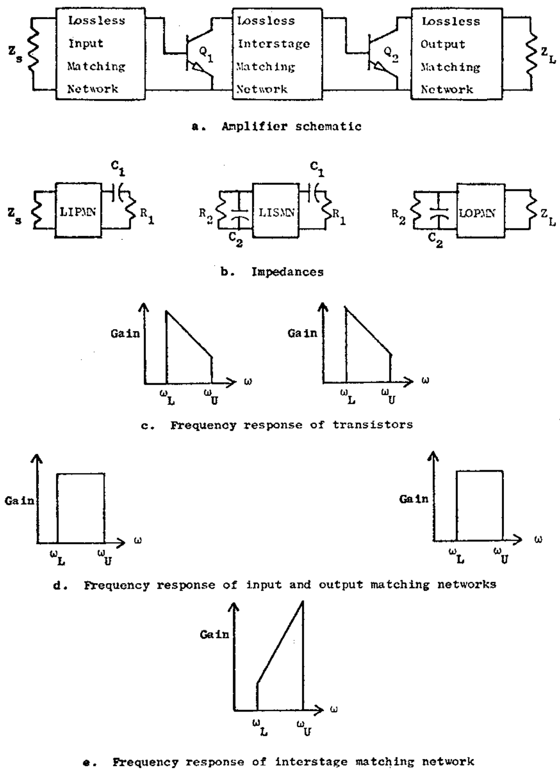

Fig. 1. CHARACTERISTICS OF A TYPICAL AMPLIFIER DESIGN PROBLEM AFTER THE UNILATERAL AND LUMPED-ELEMENT IMPEDANCE IDEALIZATIONS ARE MADE.

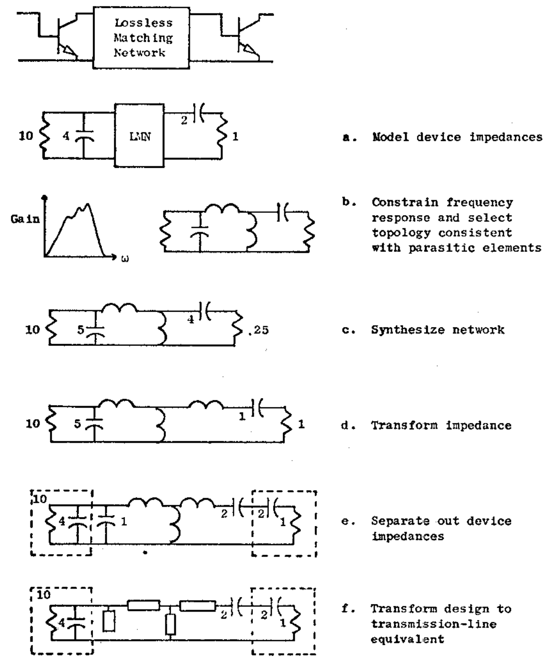

Fig. 2. OUTLINE OF MATCHING SYNTHESIS PROCEDURE.

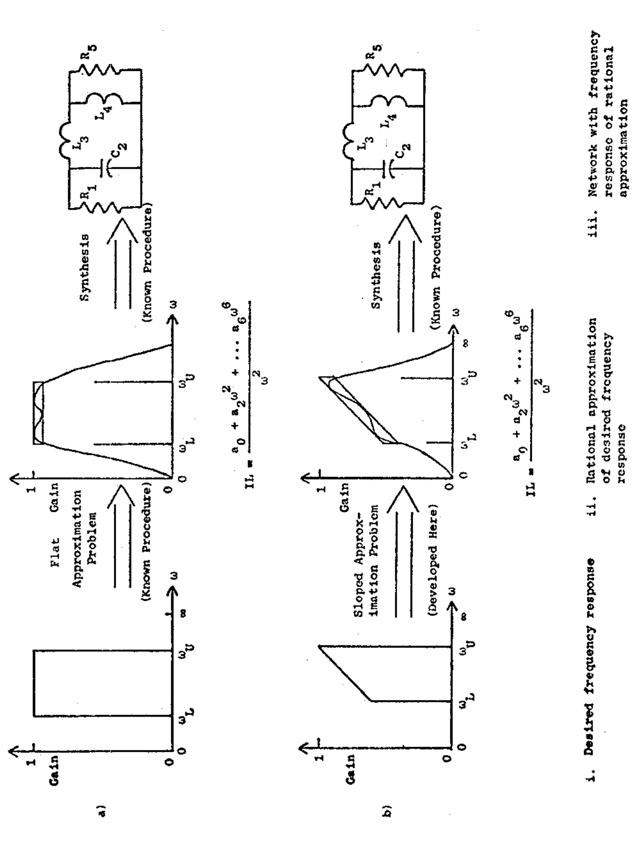

Figure 3 a) THE FAMILIAR PROCEDURE OF SYNTHESIZING A NETWORK OF FLAT PASSBAND PERFORMANCE.
b) THE SLOPED APPROXIMATION PROBLEM IS SOLVED TO YIELD NETWORKS OF SLOPED PASSBAND PERFORMANCE.

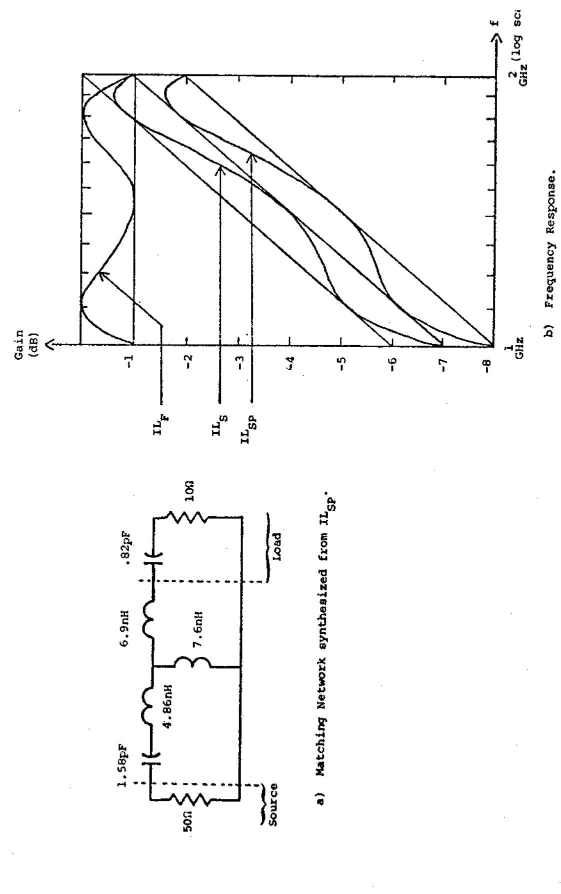

FIGURE 4. A SYNTHESIZED MATCHING NETWORK WITH 6 dB/OCTAVE SLOPE.